

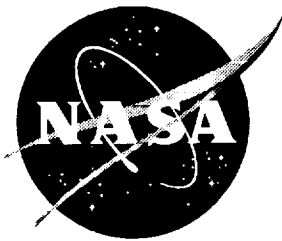
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Model-Based Automatic Generation of Grasping Regions

David A. Bloss

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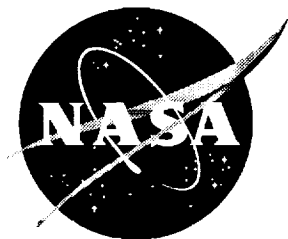
Model-Based Automatic Generation of Grasping Regions

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INTRODUCTION

Recently, there has been considerable interest in the development of multifingered robotic end effectors which could provide robots with greater dexterity than is possible with traditional, fixed structure devices [11]. One of the most fundamental questions arising from the study of such multifingered robotic end effectors is the determination of an appropriate grasp [5]. One very important notion in grasp selection is that of form closure. In the remainder of this paper, form closure will be defined as follows:

Definition: Form Closure: A fixed set of contacts on a rigid body is said to exhibit form closure if the body's equilibrium is maintained despite the application of any possible externally applied wrench (force and moment). Equivalently, the contacts prevent all motions of the body, including infinitesimal motions [12].

With this definition, a method has been developed to determine not only if a specific grasp is in form closure, but to what extent that grasp represents a form closure grasp. This allows for the comparison of several specific grasps of the same object.

In order to effectively represent the graspable points of an object, it is important to exploit the symmetries of any specific, valid grasp on that object. With this information it is possible to construct graspable regions on an object, where any grasp within that specified region will be in form closure. This allows for continuous grasping regions as opposed to many specific grasp points on an object, thereby reducing the complexity of grasp-related tasks such as tracking.

A method has been developed, given a model of the target object and of the grasping end effector, to automatically generate form closure grasp transformations from the end effector to the target object, and to associate appropriate translational and rotational symmetries with the transformation if they exist.

MODEL-BASED APPROACH

This algorithm assumes that the geometry of both the target object and the robotic end effector is known a priori in the form of a CAD model. This allows easy integration into many systems grasping diverse objects with virtually any type of end effector.

The target object models are first divided into their convex components, and these components are further divided into planar polygons. Each polygon's center and outward-facing unit normal vector is then calculated. The end effectors model is given a coordinate system with its origin at the center of the palm, Z axis aligned with the outward-facing unit normal of the palm, and Y axis pointing toward the thumb of the end effector. Once these operations have been performed on the object and end effector models, it is possible to generate initial form closure grasp transformations which will be the basis of the final grasp regions defined for the target object.

INITIAL GRASP TRANSFORMATION

The initial step in generating specific, valid grasp transformations is to place the model of the end effector at each polygon's center point, with orientation of the palm (the end effector's Z axis) opposite that of the polygon's outward facing unit normal. This proves

to be a very simple starting point that, with the addition of translational and rotational symmetries, is easily expanded into regions that span nearly all of the graspable points on the object.

An initial collision check is then performed between the end effector model and the target object model. If initial collisions are found, the end effector model is moved in its negative Z direction until no collisions exist.

The next step is to close the end effector model, until the fingers collide with other parts of the end effector or the target object, and check for form closure.

All the contacts between the target object and the end effector are modeled as "soft-finger" contacts. That is, the friction over the area of contact allows the finger to exert pure torques in addition to pure forces pointing into the friction cone. The finger can exert torques in both directions, about the normal axis of the point of contact. So the wrench convex is described by a one-sided friction cone plus a two-sided torque [8]. This assumption is made because of the types of materials coming into contact in the particular implementation of the algorithm, and is not an issue of the algorithm itself.

With this assumption, a grasp with two soft-finger contacts is form closure if and only if the segment P_1P_2 , or P_2P_1 , joining the two points of contact P_1 and P_2 , points strictly into and out of the friction cones respectively at P_1 , P_2 (figure 1) [8]. Simply enough, if a grasp has two contacts which could satisfy this condition, it is considered a form closure grasp.

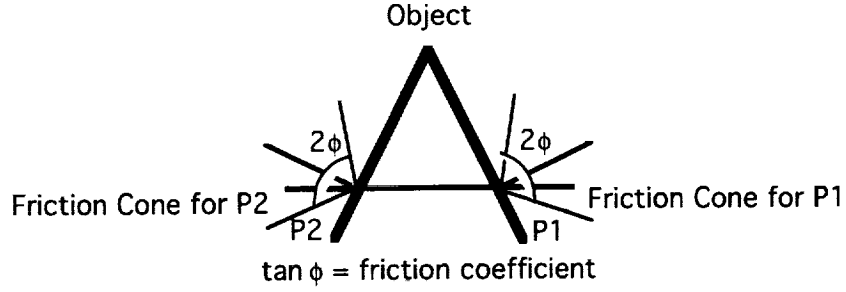


Figure 1: Form Closure with two soft-finger contacts

Next, the grasp is given a relative strength rating according to the following equation:

$$\sum_{i=0}^{\text{\# contact pairs}} 1 + \frac{K}{\text{min_dist (P1P2, Center of Target)}}$$

Once this initial rating is obtained, the end effector is rotated about its Z axis to find the particular orientation that produces the greatest strength rating. If no orientation can produce a grasp rating above zero (representing a grasp not in form closure), then that polygon's center point is disregarded as a grasp point, and the next potential point is investigated. Otherwise, the translational and rotational symmetries of the transformation (position and orientation) with the greatest relative strength rating are investigated, and a grasping region is formed.

SYMMETRIES OF THE INITIAL GRASP

There are four types of symmetries that are searched for in this algorithm, each demanding that the initial rating of each valid grasp be conserved. They are limited translational, limited rotational, unlimited rotational, and discrete rotational (figure 2).

Limited translational symmetry is recognized when an initial transformation can be translated in a direction within specified limits (figure 2a). It is tested for by simply sliding the initial transformation along its Y axis until a valid grasp rating is no longer obtained, or a collision occurs between the end effector and the target object. This leads to definition by a directional vector of translation, and the relative limits of translation.

Limited rotational symmetry occurs when an initial transformation can be rotated about a point in a direction within specified limits (figure 2b). This is tested by rotating the initial transformation about the center point of the convex component it is near in its X and Y directions. If a valid grasp rating is maintained and a collision occurs at some point in the rotation, limited rotational symmetry is recognized and defined by a rotation point, a perpendicular rotation vector, and the relative limits of the rotation.

Unlimited rotational symmetry occurs when an initial transformation can be completely rotated about a point in a given direction (figure 2c). This is tested for in the same way as limited rotational symmetry, with the obvious exception of a collision in some portion of the rotation. A rotation point and a perpendicular rotation vector are all that is needed to define this symmetry.

Finally, discrete rotational symmetry is the case where the initial transformation can be rotated π radians about its Z axis (figure 2d). The test for this symmetry is to rotate the initial transformation π radians about its Z axis and test for a valid grasp rating. This leads to definition by a rotation axis (in the objects frame).

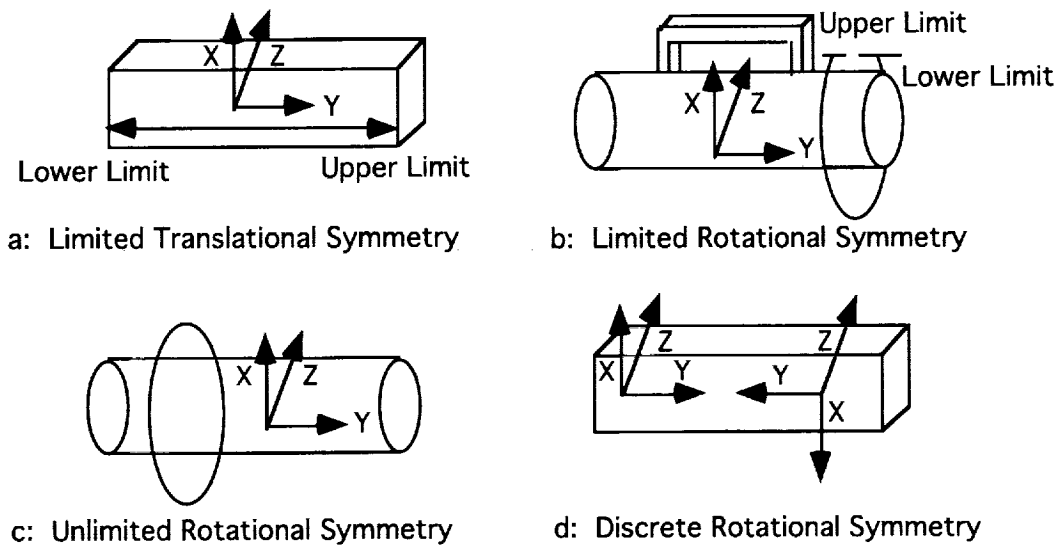


Figure 2: The four types of grasp symmetries

COMBINATION OF SYMMETRIES

The strength of this algorithm comes in the effective combination of the appropriate symmetries associated with the initial valid transformations. It is very important that, if a transformation is assigned two symmetries, these two symmetries create a continuous grasp region. Otherwise the symmetries must be separated, and two separate grasp regions formed. See figure 3 for a flow chart on how these continuous grasp regions are formed.

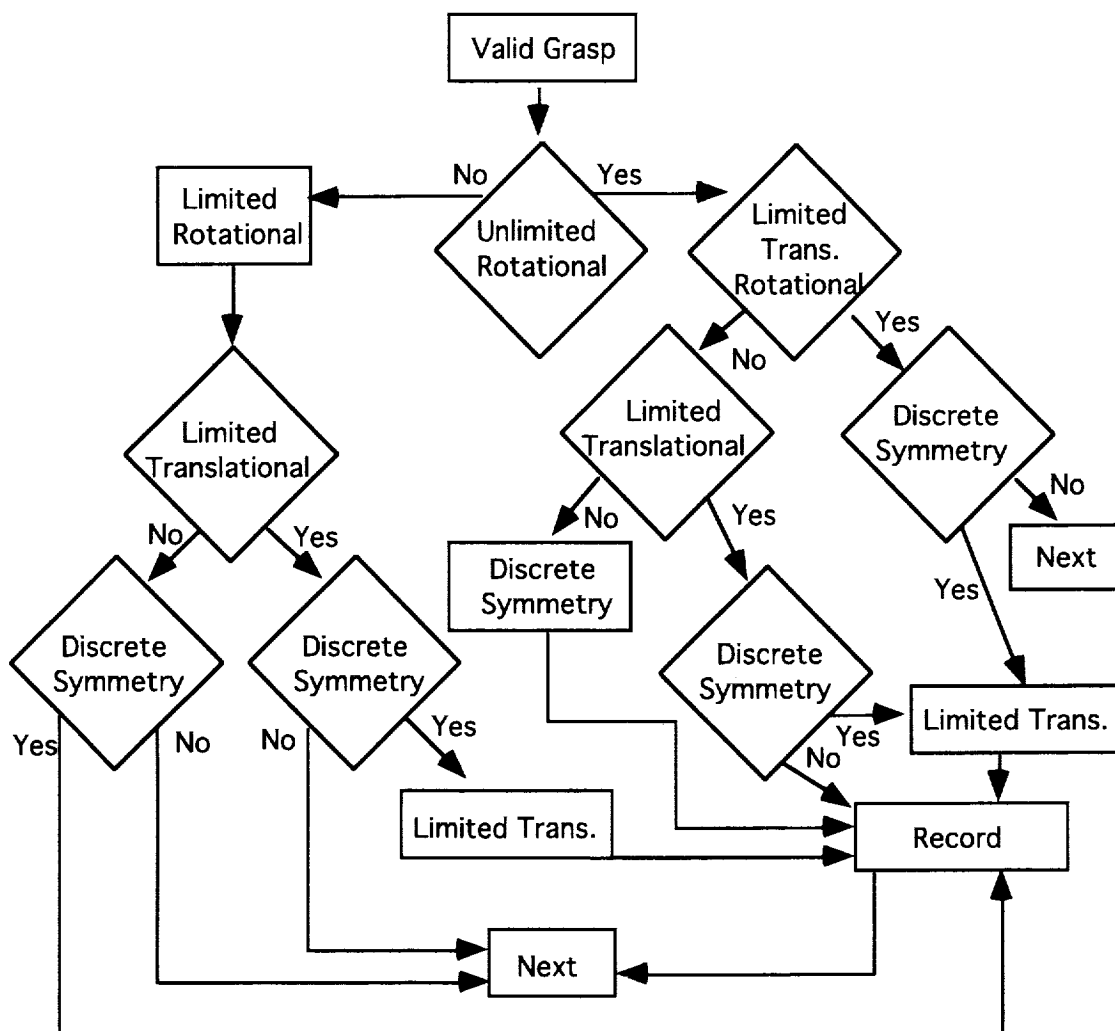


Figure 3: Formation of continuous grasp regions

CONCLUSIONS

The contributions of this algorithm are three-fold. First, it automates the process of grasp point selection. This was traditionally a tedious task performed either by trial and error, or by hand in a simulation.

Second, it defines a relative grasp rating to compare the strength of one grasp vs. another grasp of the same object. Although this is a very simple rating where "more is better," it can be easily altered to take into consideration task-based factors, thereby allowing a task-based planner to automatically select a grasping region.

Finally, it defines and effectively utilizes a set of grasping symmetries to produce continuous grasp regions as opposed to discrete grasp points. This allows for more freedom in a grasping system/subsystem in that a full region can be targeted as valid instead of trying to grasp exactly at a specified point on a target object.

This algorithm has been applied to the EVA Helper/Retriever project at the Johnson Space Center. The end effector currently in use is the Version 4 Jameson Hand, and the target objects include tools such as wrenches and ratchets, and space-specific targets such as star trackers and EMU batteries.

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